The 2007 financial crisis and the UK residential housing market: Did the relationship between interest rates and house prices change?

Tse, C-B, Rodgers, T & Niklewski, J

Original citation & hyperlink:
Tse, C-B, Rodgers, T & Niklewski, J 2014, 'The 2007 financial crisis and the UK residential housing market: Did the relationship between interest rates and house prices change?' Economic Modelling, vol 37, pp. 518-530
https://dx.doi.org/10.1016/j.econmod.2013.08.013

DOI 10.1016/j.econmod.2013.08.013
ISSN 0264-9993

Publisher: Elsevier

The 2007 financial crisis and the UK residential housing Market: did the relationship between interest rates and house prices change?

Chin-Bun Tse [#]
Salford Business School
University of Salford
Salford M5 4WT
UK
Email: C.Tse1@salford.ac.uk

Timothy Rodgers
Coventry Business School
Coventry University
Coventry CV1 5FB
UK
Email: T.Rodgers@coventry.ac.uk

Jacek Niklewski
Coventry Business School
Coventry University
Coventry CV1 5FB
UK
Email: J.Niklewski@coventry.ac.uk

#Corresponding author

Abstract

This paper investigates the impact of the 2007 financial crisis on the relationship between real mortgage interest rates and real house prices. It applies a dynamic conditional correlation based methodology that uses fractionally differenced data along with controls for structural breaks and non-interest-rate related factors that influence house prices. The key finding made is that the financial crisis had a long-term structural impact on the monetary transmission relationship. For example, we find that the mean conditional correlation between house prices in England and Wales and the three-year fixed mortgage rate rose by 6.6 percentage points. Similarly, the mean correlation between prices and the standard variable mortgage rate increased 6.4 percentage points to 54%. These findings suggest to us that interest-rate-based monetary policy still has an important role to play in the housing market.

Keywords: financial crisis, residential housing market, conditional correlation, transmission mechanism

JEL Classifications: G12, E52

Paper highlights:

- The financial crisis and the relationship between interest rates and house prices.
- A Dynamic Conditional Correlation based methodology is used.
- The crisis had a structural impact on the monetary transmission relationship.
- Interest-rate-based monetary policy is still influential in the UK housing market.

1. Introduction, Aims and Literature

The 2007 financial crisis produced major shocks in both the UK housing and mortgage markets. This paper uses a dynamic conditional correlation methodology (Engle, 2002) to examine the affect of the crisis on the conditional correlation between house prices and mortgage interest rates. This is a significant issue as any structural change in the transmission relationship could alter the effectiveness of monetary policy in the housing market.

The severity of the financial crisis on the UK was unprecedented; it resulted in nominal interest rates falling to historically low levels and it also resulted in an unparalleled contraction in the availability of mortgage credit. Its origins lay in a collapse in the US housing market that spread throughout the international financial system. Although there was no evidence of direct contagion from the US real estate crisis to the UK housing market (Hatemi and Roca, 2011), the UK started to experience falls in both the Bank of England base rate and housing loan approvals from around July 2007. The dynamics of the UK housing market are complex which means that any examination of the interest-rate-related price effect of the crisis will need to account for, and control for, the impact of other influences on house prices. These will include the affects of the deterioration in consumer confidence associated with the perceived increase in the threat of unemployment and also of substitution between the rental and owner-occupation sectors. We also take into consideration in this paper the impact of differences in the speed and extend of adjustment in the different types of mortgage finance instruments used in the UK and we also examine for the possibility of regional variations in the reaction of the housing market.

The relationship between interest rates and house prices under what can possibly be described as 'normal conditions' has been extensively debated in the literature. Levin and Pryce (2009) argued that UK house prices increases over the period 1996-2007 were driven by real interest rates and Ho and Wong (2008) demonstrated that in Hong Kong house prices were driven by the local equivalent of the UK central bank base rate. Fitzpatrick and McQuinn (2007) also identified a long-run mutually reinforcing relationship between house prices and mortgage credit. It should also be noted that other research suggests that the relationship between interest rates and house prices might not be so clear cut. For example, Gilchrist and Leahy (2002) argued that monetary-policy-related interest rate movements have little direct effect on asset prices. This is however, perhaps only a minority view. Giuliodori (2005) examined the relationship between interest rate shocks and house prices across Europe between 1979 and 1998. It was found that the impulse response to a 100 basis point shock varied considerably between countries. The UK however, was found to have a relatively large maximum response of about two percentage points after a lag of around 10 periods. Tsatsaronis (2004) examined data from 1970 to 2002 and found similar results using a variance decomposition methodology; the UK was found to be in a group of countries where a one percentage point fall in short term interest rates would increase house price inflation by about 2.6 percentage points.

It is well documented elsewhere in the literature that bank lending plays a significant role in the monetary transmission mechanism. Goodhart (1995) found that property prices significantly affect credit growth in the UK and Hofmann (2004) also argued that property prices are important in determining long-run borrowing capacity in the private sector. In a follow-up study Goodhart and Hofmann (2008) found evidence of a Pan-European multidirectional link between house prices and monetary variables (nominal changes in broad money supply and interest rates), with the strength of the linkages found to be stronger in more recent years (1985-2006). Findings such as these appear to imply that in examining the relationship between interest rates and house prices in this paper, we will need to take careful consideration of a number of monetary related variables.

What is perhaps less well documented in the literature is how financial and economic extreme events, like the 2007 financial melt-down, can influence the nature of the monetary transmission mechanism. Su et al. (2012) found that real estate market efficiency tends to vary considerably over time and in a further study Wong et al. (2003) suggested the causal relationship between house prices and interest rates can switch during economic cycles. In an examination of extreme events Tsai and Chen (2010) found that in USA, the correlation between the Federal Fund Rate and real house prices changed significantly in response to a series of extreme events (for example, a stock market crash). European studies also found that changes in the relationship between house prices and interest rates might be expected in response to extreme shocks; for example, Bjørnland and Jacobsen (2010) found that Norwegian, Swedish and British house prices reacted immediately and strongly to monetary policy shock. It should be noted that the previous paper cited does not fully address an issue that we feel is fundamental in modelling the relationship between interest rates and house-prices during periods of crisis; namely, it does not explicitly model the time lags involved.

Further studies have identified regional differences in the transmission relationship. Allen et al. (2009) reported that house price movements in Canadian cities from 1985 to 2007 were not cointegrated and a study on the Swedish housing market by Wilhelmsson (2008) found that the impact of interest rate adjustments on prices varies considerably on a regional basis. Some research has suggested that regional price differences are driven mainly by non-interest rate factors. For example, Robson (2003) found that regional house price differences were related to regional unemployment rates and that the transmission mechanism operated through the flows into and out of regional unemployment. If this is the case, we believe that the 2007 financial crisis will possibly moderate this process through the reduction in the availability in mortgage credit reducing labour mobility. One employment-linked reason why the 2007 financial crisis may possibly show regional differences is that larger numbers of people are employed in the financial services industry in the London and the South East regional economies than in the rest of the country. We may possibly therefore observe time-lagged regional variations in the impact on house prices.

The rest of this paper is organised as follows: Section 2 provides an overview of the impact of the financial crisis on the UK housing market. Section 3 identifies the hypotheses tested and Section 4 describes and discusses the methodology. Section 5 presents the empirical findings and discusses their implications. Finally, Section 6 draws some conclusions about the impact that the financial crisis has had on the transmission relationship.

2. The Financial Crisis and the UK Housing Market

The housing market plays an important role in UK economic activity and this is reflected in a high owner-occupation rate. According to the Royal Institute of Chartered Surveyors (2010) this stood at 68% in 2010. Although this was high by international standards, the rate had fallen by 3 percentage points from the 2003 level. They put this down to 'stretched affordability'; specifically, that the ratio of house prices to income was well above the historical average. This stretching of affordability made it particularly difficult for first-time-buyers to enter the market.

The 'credit crunch' associated with the financial crisis meant that as well as the issue of affordability, the UK market faced a further problem relating to the supply of finance. Prior to the financial crash borrowers were able to finance up to 95% (and sometimes more) of the purchase price using mortgage debt. Post-crash, banks withdrew the majority of these offers and many increased the required down-payment to around 25% compared to a historical average of 10%[1].

Data from the British Banking Association (2012) shows that as the credit crunch took hold monthly loans secured for house purchases (as opposed to those for re-mortgaging existing property) fell from £11,935 million (78,196 approvals) in November 2006 to a low of £2,062 million (17,297 approvals) in November 2008. By July 2012 this had recovered somewhat to £4,550 million (28,818 approvals) but this was still well below the historical average.

Even if credit eventually becomes more readily available the housing market appears unlikely to return to pre-crisis levels. The UK Financial Services Authority (FSA) introduced proposals to place greater formal restrictions on mortgage lending. The Council of Mortgage lenders[2] suggested in 2011 that implementation of these proposed restrictions could see four million less mortgages in the UK (halving of the total number) over the subsequent 4 years.

The question that this paper asks is whether or not the changes brought about by the financial crisis has had a long term structural impact on the relationship between interest rates and house prices. This question is important as it raises issues as to how effective future official monetary policy can be in influencing the market.

Any examination the UK mortgage market needs to take into account the fact there are a number of different types of mortgages available and that these can have significantly different interest rates. According to NMG Financial Services Consulting, 48% of the mortgages outstanding in 2010 were fixed[3]; this suggests that when the financial crisis struck changes in the Bank of England base rate had no immediate effect on the repayments of about half of borrowers. It can also be noted that the relationship between mortgage-interest-rates and money-market-interest-rates became unusually volatile once financial crisis began. For example, the two-year discount rate is usually closely linked to the two-year swap rates. However, Moneyfacts.co.uk[4] highlights that at the end of November 2009 the difference between the two-year swap rate (2.04% at the time) and the average two-year fixed rate (5.18%) was the widest on record.

[1] Source: http://www.communities.gov.uk/documents/507390/pdf/1221553.pdf. Access date: 16/12/2011.
[2] Source: http://uk.finance.yahoo.com/news/fsa-reforms-would-have-meant-4m-fewer-mortgages-lenders-claim-tele-59ce0319f77b.html?x=0. Access date: 10/15/2011.
[3] Source: http://www.telegraph.co.uk/finance/economics/8197806/Low-interest-rates-failing-to-rescue-British-households-from-1.45-trillion-debts-says-Bank-of-England.html. Access date: 17/09/2011.
[4] Source: http://moneyfacts.co.uk/news/mortgages/rates-on-two-year-fixed-mortgages-fall/. Access date: 18/11/2011.

For the purpose of this study monthly data is used; this runs from January 2000 to March 2013. Mortgage interest rates are represented with three of the most widely used instruments at the time of the 2007 crisis. These are: the real three-year fixed rate (3YF), the real two-year discounted rate (2YD) and the real standard variable rate (VR). For benchmarking purposes we also include the real Bank of England base rate (BR). The data is sourced from the Bank of England statistical interactive database[5] and all values are deflated by the Retail Price Index[6] to convert them into real terms. From Figure 1 it can be identified that after the BR began to be cut in July 2007 there was a significant divergence between the real BR and real fixed mortgage rates. It can also be noted that for the first time in many years the standard variable rate was no longer appreciably higher than comparable fixed-rate and discount products.

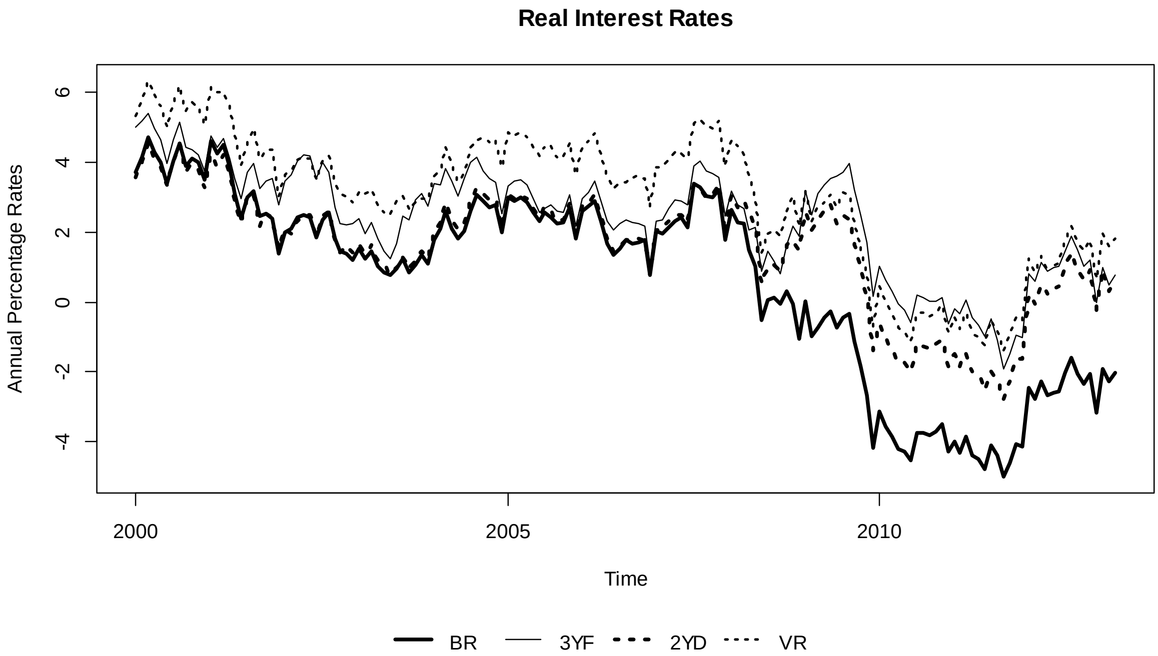


Figure 1: Real base rate and selected fixed and variable real mortgage interest rates from January 2000 to March 2013 (nominal values adjusted for inflation).

For our house price data series we use adjusted monthly data sourced from Acadametrics house price indices[7]. All values are deflated by the Retail Price Index. The response of real house prices to the financial crisis can be seen in Figure 2. From the middle of 2007 real prices across England and Wales began to fall; as is shown by the Real Prices All Areas (PALL) series. The impact appeared to be fairly similar in South East England (PSE) region and the less affluent East Anglia (PEA) and West Midlands (PWM) regions, this despite the stronger connections between the South East and the financial services sector.

[5] Source: http://www.bankofengland.co.uk/mfsd/iadb/NewInterMed.asp. Access date: 03/05/2013.
[6] Source: http://www.statistics.gov.uk/default.asp. Data code: CHMK (RPI excluding mortgage interest payments). Access date: 03/05/2013.
[7] Source: http://www.acadametrics.co.uk/about.php. Access date: 03/05/2013. The index is estimated from the full set of residential property prices actually transacted in England and Wales. The prices used are those recorded on the Land Register. The monthly index values are smoothed (over a rolling 3 month period), seasonally (purely seasonal variation) adjusted and mix (type of house) adjusted.

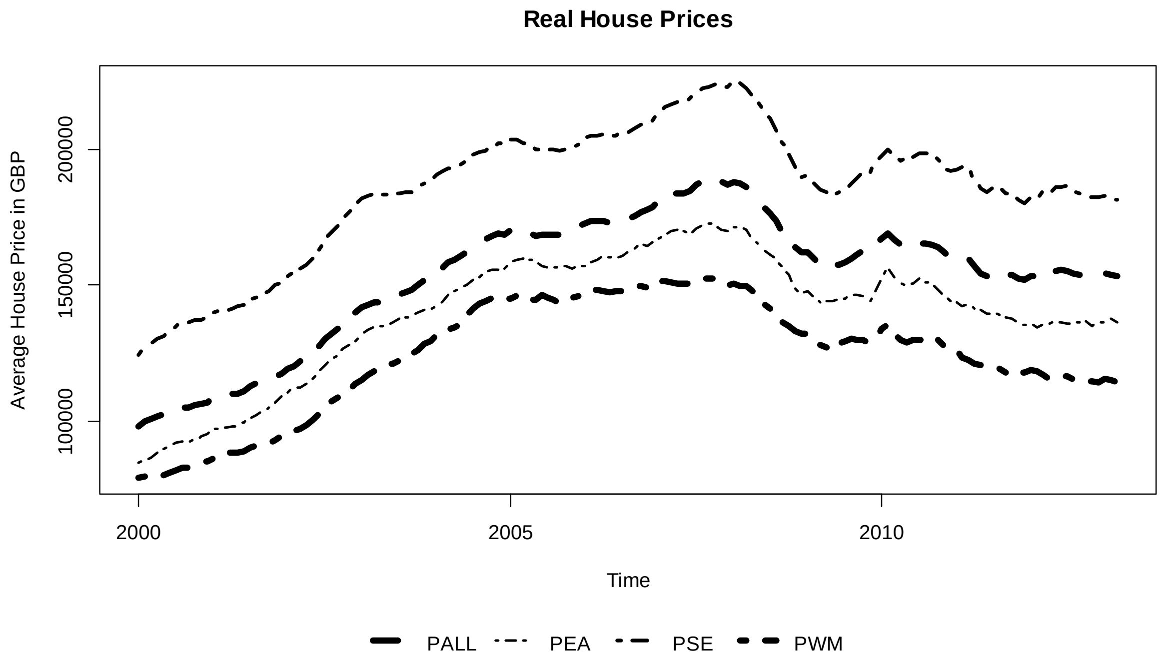


Figure 2: Real UK house prices from January 2000 to March 2013 (nominal values adjusted for inflation).

Figure 3 shows the relative changes in Real Prices All Areas (PALL) and real interest rates from a base year of 2000. It can be noted that after 2007 the relationship became a lot more volatile.

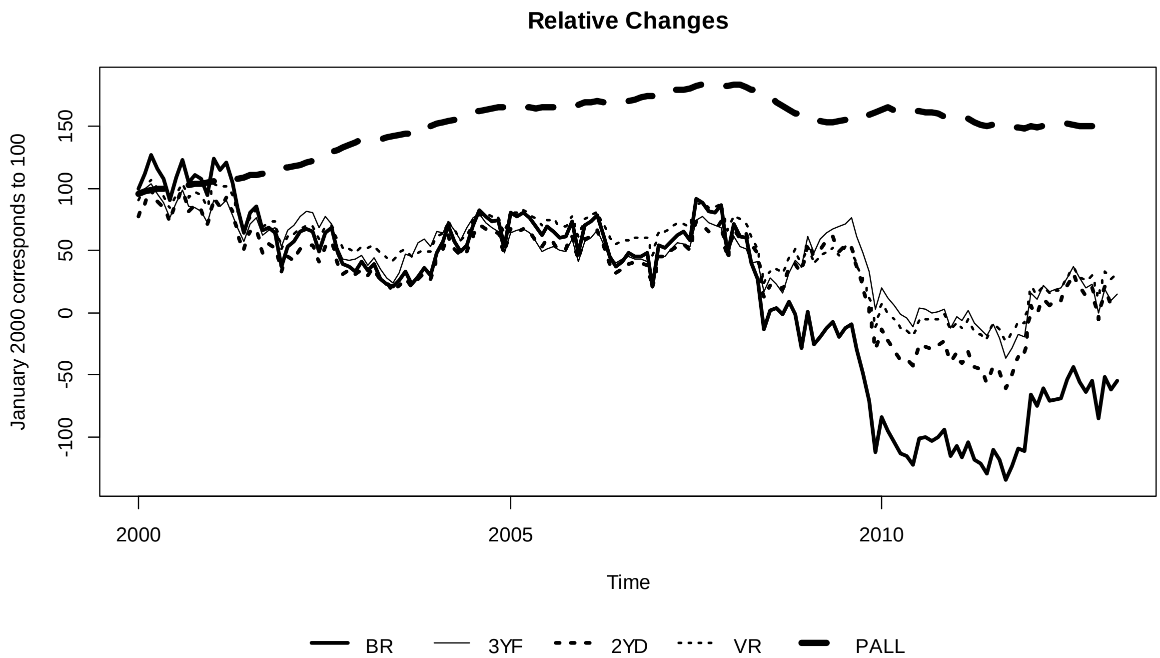


Figure 3: Relative changes in real UK house prices and real interest rates from January 2000 to March 2013.

The increase in the volatility of the relationship may possibly reflect the increasing importance of a number of additional influences on the housing market. Bouchouicha and Ftiti (2012), for example, argued that in the UK wealth effects can be a significant transmission channel during market downturns. Other possible influences emanating from the 2007 crisis can also be identified. There is evidence to suggest that the quantity constraint on the availability of credit resulted in a substitution effect away from owner-occupation towards the rental sector and, in addition, a second substitution effect in the form of owner-occupiers extending their houses rather than trading-up. Private sector rents increased at a much faster rate than inflation during this period; for example, the Rentright Rental Retail Price Index shows nominal average monthly rents increasing from £771 in March 2007 to £1,112 in September 2010 and £2,362 by September 2012[8]. Further evidence is provided by one of the country's largest rental agencies, Countrywide, which reported large increases in the numbers of tenants registering with it over this period; for example, a 16% increase in the first quarter of 2010[9]. Evidence to suggest owner-occupiers started improving their houses as an alternative to trading-up market can also be found in planning applications data. As the credit crunch started to take hold the number of planning applications in England initially fell substantially. They began to rise significantly again from quarter two of 2010 at the same time as the number of new loans approved for house purchase continued to fall[10]. Industry sources have identified that about 60% of the applications in this period were for small house extensions[11].

A further factor that may have had a negative influence on housing market transactions over this period is the impact of the threat of increases in unemployment. The importance of this issue on transactions has been well documented in the literature (Abelson et al., 2005). As the crisis developed (and the threat of unemployment rose) in the UK consumer confidence fell; significant falls began about March 2008 and confidence remained low well into 2012[12].

The conclusion we draw is that the apparent loosening of the relationship between real house prices and real interest rates found in the data suggests that a number controls will be required in order for our study to accurately model the relationship between real house prices and real mortgage interest rates.

[8] Source: http://www.rentright.co.uk/. Access date: 12/11/2012.
[9] Source: http://www.countrywide.co.uk/media/press-release.aspx?id=150ffc72-79d4-4768-81b7-ec551bf99c45. Access date: 12/11/2012.
[10] Table P120: District planning authorities 1 - Planning applications received and decided by speed of decision, England and Wales. Source: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7234/2136336.pdf. Access date: 11/11/2010. Second source: British Banking Association (2012).
[11] Source: http://www.building.co.uk/data/house-extensions-drive-recovery-in-planning-applications/5020706.article. Access date: 11/11/2012.
[12] GfK Consumer Confidence Index. Source: Thomson-Reuters Eikon. Access date: 03/05/2013.

3. Hypothesis Tested

Both Levin and Pryce (2009) and Harris (1989) argued that house price movements are driven by real interest rate changes. They interpreted increases in house prices associated with falls in real interest rates as a consumer response to falling real costs. With interest rates falling to unprecedented levels as a result of the 2007 crisis real interest rates became strongly negative. In normal circumstances this would be expected to be associated with real house prices increasing. However, the ‘mortgage famine’ associated with the credit crunch along with falling consumer confidence and substitution to the rental market meant that negative real interest rates failed to stimulate extra demand. Our expectation is therefore that the crisis has resulted in a long-term structural adjustment in the correlation. This provides the basis for our principal hypothesis:

Hypothesis 1: The financial crisis resulted in a permanent change in the correlation between real interest rates and real house prices.

It was identified by Wilhelmsson (2008) that regional differences may develop in the relationship between mortgage rates and house prices. This was explained in terms of differences in the ways in which regional economies adjust to events like a financial crisis. On this basis we speculate that as people employed in financial services sector are located primarily in the London and South East, the 2007 crisis may have elicited region-based differences in housing market responses. This provides the basis for our second hypothesis:

Hypothesis 2: Structural adjustments in the relationship between real house prices and real interest will show regional variation.

In addition to our two main hypotheses preliminary tests are undertaken to establish whether there has been a structural change in the relationship between the Bank of England base rate and mortgage interest rates. This is an important issue to examine as any change in this relationship would have the potential to affect the ability of the monetary authorities to influence house prices through the interest rate channel.

4. Methodology

For the purposes of this paper, the financial crisis is deemed to have started in July 2007 which is when the financial authorities began to reduce BR to mitigate the impact of the 'credit crunch'. The impact of the crisis is modelled up to March 2013 (the full data-set currently available). We make no attempt to identify an ending point of the crisis as the primary objective of the paper is to determine its possible structural impact. We note that changes in the mortgage market can be identified that appear to be structural. For example, the proportion of new loans with a loan-to-value ratio of more than 90%[13] starting to fall appreciably as the crisis developed and reached a low of 1.43% in the last quarter of 2009. By the second quarter of 2012 these had only risen marginally to 2.31%; still nowhere near pre-crisis levels (14.14% at 2007 quarter 1).

Identifying which statistical methodology should be applied in a study such as this has to be considered with care. Mazouz et al. (2009), for example, in their examination of large price shocks on Asian stock markets, found significant differences in results using alternative statistical modelling procedures. A number of previous studies in this area have used structural vector autoregression (SVAR) related methodologies to examine the impact of shocks to the financial system (Van Aarle et al., 2003). Although SVAR enables an examination of transmission relationships using concurrent correlations, unlike our preferred multivariate GARCH approach, it does not enable the examination of time-varying correlations. Use of GARCH also allows the introduction of control variables in the mean equation to control for the impact of non-interest-rate factors on house prices.

Our paper applies the dynamic conditional correlation multivariate GARCH model (DCC-MGARCH) proposed by Engle (2002). Two models are developed. The first examines the relationship between the Bank of England's principle policy variable (Base Rate) and a series of mortgage interest rates. The second examines the relationship between these mortgage interest rates and house prices.

Our hypotheses are tested by examining the data for statistically significant changes in correlations. For robustness we consider two approaches to testing. First, the estimated conditional correlations are regressed against a dummy variable that represents the period from the start of the crisis onwards; this dummy variable is then tested for statistical significance. Second, we use two statistical-location based tests[14]. We believe these testing methodologies to be appropriate as the impact of the financial crisis cannot be seen in terms of a one-off shock; rather it was a process that developed momentum over a number of months.

4.1 Model Specification and Discussion

All the variables used are adjusted series. They were transformed into natural logarithms[15] and Zivot-Andrews unit root tests were applied. These tests identified non-stationarity in the

[13] Source: British Bankers Association (2013).

[14] A similar approach was used by Celik (2012) in the context of identifying the impact of the same crisis on foreign exchange markets. The location-based tests applied in our paper are the Welch (1938) two-sample mean comparison t-test and the Wilcoxon (1945) rank-sum test which compares the location parameters of the two samples. It can be noted that Welch test takes non-equality of variances into account and the Wilcoxon test is robust to non-normality in the distribution, non-equality in the variance and also for small sample sizes (Sawilowsky, 2005).

[15] 10 is added to real interest rate series and 50 to the Consumer Confidence Index to adjust for negative terms.

series along with potential breaks in the data (information used subsequently in the mean equations). The data was de-trended using exponential moving averages with a smoothing factor of 0.1 and fractional integration parameters were then estimated for the residual components using maximum likelihood[16]. These parameters were used to fractionally difference the series in order to ensure their stationarity (following Bollerslev et al*.,* 2012).

The estimation of conditional correlations using the DCC model was a multi-step procedure where we used the residuals from a series of VAR-based mean equations[17] to estimate conditional volatilities. The DCC model parameters were subsequently estimated from residuals standardised by their conditional standard deviations.

Model 1 (Appendix 1) was used to estimate the conditional correlation between the Bank of England base rate and the three mortgage interest rate series identified in Figure 1. The 3 pairs of mean equations consist of VAR relationships between the base rate and the individual mortgage interest rates. There are also 3 pairs of corresponding variance equations. Model 2 is used to estimate the correlations between the 3 individual mortgage interest rates and the 4 sets of house price series shown in Figure 2. This results in 12 pairs of mean and variance equations. Due to space limitations Appendix 2 shows only the VAR pairs between PALL and the 3 mortgage interest rates. The results associated with the remaining pairs are available from the authors on request.

Mean Equation Specification

Model 1 uses 3 pairs of bi-variate Vector Autoregressive (bi-VAR) equations in respect to: BR & 3YF, BR & 2YD and BR & VR.

$$y_{i,t} = \mu_i + \sum_{k=1}^{p} \sum_{j=1}^{2} \gamma_{i,j}^{k} y_{j,t-k} + \delta_i BREAK_t + \varepsilon_{i,t} \qquad [1]$$

Where $y_{i,t}$ (i = 1) represents the real base rate and $y_{i,t}$ (i = 2) represents the 3 mortgage interest rates. The lag order p is identified by Hannan-Quinn (HQ) information criterion[18]. The external dummy variable ($BREAK$) represents structural breaks[19] in the data; these were identified by the Zivot-Andrews unit root test as occurring in 2009[20]. Due to the close proximity of the breaks in all interest rate series a single break-point of August 2009 is used across all models.

Model 2 uses 12 pairs of bi-VAR models in respect to: PALL & 3YF, PALL & 2YD, PALL & VR, PEA & 3YF, PEA & 2YD, PEA & VR, PSE & 3YF, PSE & 2YD, PSE & VR, PWM & 3YF, PWM & 2YD and PWM & VR.

$$\begin{aligned} y_{i,t} = \mu_i + \sum_{k=1}^{p} \sum_{j=1}^{2} \gamma_{i,j}^{k} y_{j,t-k} + \delta_{i,1} BREAK_t + \delta_{i,2} RENTSUB_t + \delta_{i,3} CONFID_t + \\ + \delta_{i,4} CONFID_{t-1} + \delta_{i,5} CONFID_{t-2} + \delta_{i,6} CONFID_{t-3} + \varepsilon_{i,t} \end{aligned} \qquad [2]$$

[16] ARFIMA (0,d,0) with d values: 0.494 (BR), 0.492 (3YF), 0.494 (2YD), 0.493 (VR), 0.500 (PALL), 0.499 (PEA), 0.499 (PSE), 0.500 (PWM), 0.495 (CONFID).

[17] An approach also used, for example, by Dajcman (2012) in respect to examining spillovers between stock markets and also by Savva (2009) in examining international stock market interactions.

[18] Khim and Liew (2004) indentify the HQ criterion to produce superior estimates for sample sizes over 120 (our sample is 159).

[19] Lean and Teng (2013), in a Malaysian context, also model structural change using a dummy variable in the mean equation.

[20] BR: Aug 2009, 3YF: Sep 2009, 2YD: Aug 2009 and VR: Aug 2009.

Where $y_{i,t}$ (i = 1) represents real house prices for the 4 regional markets identified in Figure 2 and $y_{i,t}$ (i = 2) represents the 3 real mortgage interest rate series. The lag order p is identified by HQ information criterion. The external dummy variable (*BREAK*) controls for the structural breaks identified by the Zivot Andrews test[21]; these coincide with the period of credit tightening that resulted in reductions in mortgage loan approvals. Additional external variables are added in the mean equations to control for the non-interest-rate influences on house prices that were identified in Section 2. The variable *RENTSUB* represents a substitution effect between the owner-occupier and rental markets; this equals 1 for t ≥ February 2010[22]. The variable *CONFID* (lags 0, 1, 2, 3) is used to control for the impact of the crisis on consumer confidence in the housing market. It should also be noted that in order to aid convergence of the model scaling issues meant that interest rates and the consumer confidence index had to be divided by 6 and 15 respectively. It can also be noted that as the breaks in the interest rate series coincide with the rental substitution period they are omitted from the model.

Variance Equation Specification

The residuals, which are assumed to be conditionally multivariate-normal[23] in both Model 1 and Model 2, are used to estimate the conditional variance (Equation [3]). Following Cappiello et al. (2006) we test for the most efficient asymmetric model using information criterion[24]. The models tested are part of the set of GARCH models first identified by Hentschel (1995) and subsequently described by Ghalanos (2013a) as the family GARCH (fGARCH) model.

$$\sigma_t^\lambda = \left(\omega + \sum_{j=1}^{m} \zeta_j \upsilon_{jt}\right) + \sum_{j=1}^{q} \alpha_j \sigma_{t-1}^\lambda \left(\left|z_{t-j} - \eta_{2j}\right| - \eta_{1j}\left(z_{t-j} - \eta_{2j}\right)\right)^\delta + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^\lambda \quad [3]$$

Where: σ_t is the conditional standard deviation, ω the intercept, υ_j external regressors, z_t the standardised residuals, η_{1j} the rotation parameter, η_{2j} the shift parameter, δ the asymmetry power parameter, λ the conditional sigma power parameter, α the ARCH parameter and β the GARCH parameter.

Based on coefficient restrictions the following sub-models can be obtained:

- GARCH (Bollerslev, 1986) when $\lambda = \delta = 2$ and $\eta_{1j} = \eta_{2j} = 0$
- Absolute Value GARCH (AVGARCH) model (Schwert, 1990; Taylor, 1986) where $\lambda = \delta = 1$ and $\left|\eta_{1j}\right| \leq 1$
- GJRGARCH model (Glosten et al., 1993) when $\lambda = \delta = 2$ and $\eta_{2j} = 0$
- Threshold GARCH (TGARCH) model (Zakoian, 1994) when $\lambda = \delta = 1$, $\eta_{2j} = 0$ and $\left|\eta_{1j}\right| \leq 1$

[21] PALL: Jan 2008, PEA: Feb 2008, PSE: Jan 2008, and PWM: Mar 2008.
[22] The numbers of seasonally adjusted mortgage approvals for house purchases showed signs of recovery during 2009 but began to fall again from January 2010. This corresponded to increases in rents. The RentRight Rent Retail Price Index (RRPI) showed rents to be broadly flat from about February 2008 until February 2010 which saw the first significant increase. We use this date to identify the beginning of significant substitution between the owner-occupier and rental sectors.
[23] The assumption of multivariate normality is not required for consistency and asymptotic normality of the estimated parameters (Engle and Sheppard, 2001).
[24] To be consistent with other elements in the paper we use HQ and assume p=1 and q=1.

- Nonlinear ARCH (NGARCH) model (Higgins et al., 1992) when $\lambda = \delta$ and $\eta_{1j} = \eta_{2j} = 0$
- Nonlinear Asymmetric GARCH (NAGARCH) model (Engle and Ng, 1993) when $\lambda = \delta = 2$ and $\eta_{1j} = 0$
- Asymmetric Power ARCH (APARCH) model (Ding et al., 1993) when $\lambda = \delta,\ \eta_{2j} = 0$ and $|\eta_{1j}| \leq 1$
- Full GARCH (ALLGARCH) model (Hentschel, 1995) when $\lambda = \delta$

DCC Equation Specification

The conditional correlation DCC model (Equation [4]) follows Engle (2002).

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha z_{t-1} z'_{t-1} + \beta Q_{t-1} \quad [4]$$

Where: z_t represents residuals standardised by their conditional standard deviation, $\bar{Q}$ is the unconditional correlation matrix of z_t, Q_t is the conditional covariance matrix of z_t and α and β are nonnegative scalars satisfying the constraint $\alpha + \beta < 1$.

Model Discussion

The adequacy of model specifications are indicated by Portmanteau tests for standardised residuals and squared standardised residuals (Q statistic Ljung-Box test, 1978) and also by ARCH LM tests (Engle, 1982) for squared standardised residuals (See Appendices for details).

The optimal lag lengths of the VAR-based mean equations are derived from HQ Information Criterion using a maximum lag specification of 36. The optimal values ranged between 1 and 2 months for Model 1 and between 12 and 19 months[25] in Model 2. The lag lengths in the second model are consistent with our expectation that the reaction time between interest rate changes and their impact on house prices would be relatively long. Although the structural break dummy variable (*BREAK*) is not statistically significant in Model 1 it is significant (and parameter signs are consistent) in 13 out of 24 equations in Model 2. This provides some support for the presence of structural breaks in the Model 2 fractionally differenced series.

The optimal volatility equations were also chosen using HQ information criterion. These are found to be TGARCH and NGARCH in Model 1 and GARCH, TGARCH and GJRGARCH in Model 2. We found the GARCH specification is optimal in 16 out 30 volatility equations. This is consistent with what Babikir et al. (2012) found in a South African context. They argued that this was possibly because GARCH (1, 1) best described the relatively even distribution of positive and negative shocks observed during the financial crisis. It can also be noted that a number of the volatility-equation coefficients in Appendix 1 and Appendix 2 are not significant; this is especially the case in relation to the α parameter. This may possibly be due to sample-size effects (Javed and Mantalos, 2013; McClain et al., 1996) that reflect our relatively small sample of 159. Limited levels of significance can sometimes also be due to

[25] This is for all 12 VAR pairs. It should be noted that only 3 representative pairs are presented in Appendix 2.

data over-whitening. To mitigate this we used a relatively low value (0.1) for the smoothing parameter.

Persistence[26] is high in Model 1. Although the minimum is 0.992 the model still mean reverts. Persistency was less of an issue in Model 2, with values ranging between 0.748 and 0.999 in persistent pairs. It can also be noted that a number of the Model 2 pairs showed an absence of persistence. For example: PSE & 2YD (0.095), PWM & SV (0.104) and PEA & SV (0.189). Full details are available from the authors on request.

The DCC equations show significance in terms of β in both models. The β term represents the decay parameter and α represents the news parameter (Engle and Sheppard, 2001). The insignificance of α in the second model implies that the news parameter is not significant. This could possibly be due to the sample size effect mentioned above. For all pairs $\alpha < \beta$. The shocks to correlations are relatively highly persistent with the half-life ranging from 1.26 to 14.40 months in Model 1 and from 6.65 to 55.97 months in Model 2[27].

[26] Following Ghalanos (2013a) the model persistence is calculated as $\sum_{j=1}^{p} \beta_j + \sum_{j=1}^{q} \alpha_j \xi_j$. With ξ_j being the expected value of the standardised residuals z_t under the Box-Cox transformation of the absolute value asymmetry term, $\xi_j = \mathrm{E}\left(\left|z_{t-j} - \eta_{2j}\right| - \eta_{1j}\left(z_{t-j} - \eta_{2j}\right)\right)^{\delta} = \int_{-\infty}^{\infty} \left(\left|z_{t-j} - \eta_{2j}\right| - \eta_{1j}\left(z_{t-j} - \eta_{2j}\right)\right)^{\delta} f(z, 0, 1, \dots) dz$ where f is the standardised conditional density.

[27] Persistence is measured as the half-life of shock computed as ln(0.5)/ln(α+β) as suggested in Engle and Sheppard (2001). The half-life is defined as the time at which a shock to correlation is expected to be halfway dissipated.

5. Empirical Findings and Discussion

Before the main hypotheses are examined we consider the impact of the financial crisis on the relationship between the BR and mortgage interest rates. Any breakdown in this relationship would potentially have significant consequences for the ability of monetary policy to influence house prices through this channel.

The conditional correlations between BR and the three key real mortgage rates are derived from Model 1 (Appendix 1) and shown in Figure 4. These, along with the series referred to in subsequent sections of this paper, are in adjusted fractional difference form. It can be noted from Figure 4 that the correlations show some degree of volatility; for example, in respect to the three-year fixed mortgage rate the values range from 0.796 to 0.983. It can also be noted that a negative short-term spike occurred at December 2008. This is consistent with the evidence presented in Section 2 which suggested that the relationship had become looser around this time. Although the correlation with the BR fell substantially for all three mortgage rates the fall proved to be short lived.

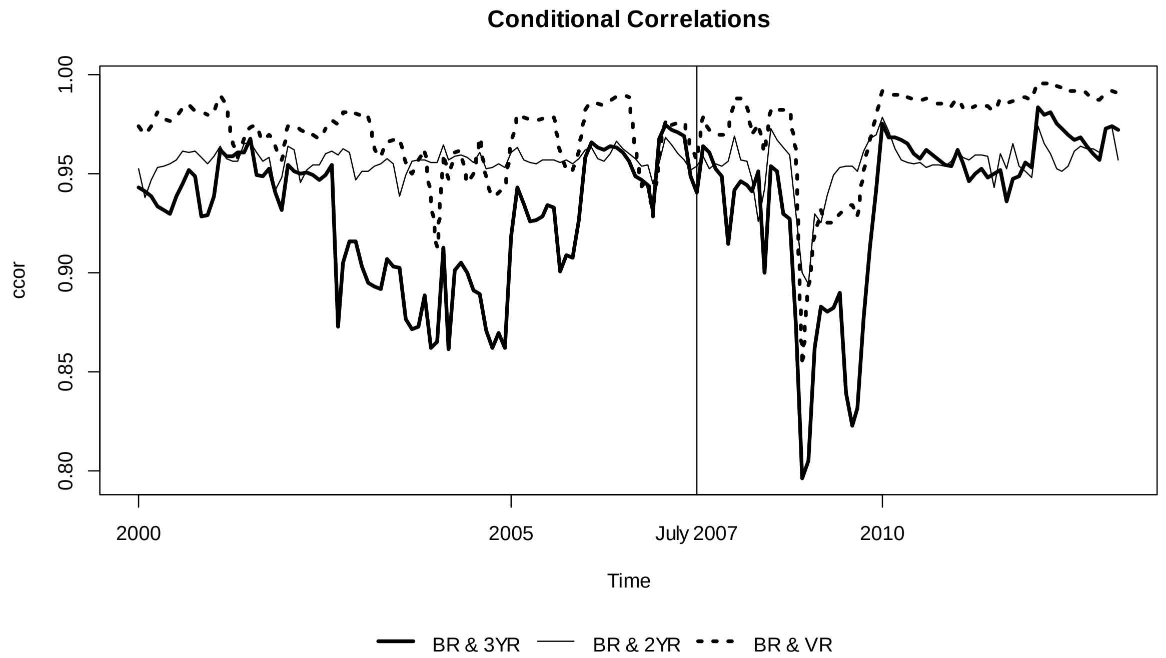


Figure 4: Conditional correlation from January 2000 to March 2013 between real base rates (BR) and: real 3-year fixed rates (3YR), real 2-year discount rates (2YR) and real standard variable rates (VR). All series are adjusted and in fractional difference form. The financial crisis is identified as starting in July 2007 (the vertical line).

Table 1a shows mean correlations for the 68 months immediately prior to the financial crisis (to July 2007) and for the 68 months up to March 2013. It shows that the mean correlation of BR with the respective mortgage interest rates changed only very marginally between the two periods and that there was no consistency between the three mortgage rates in terms of either the direction or statistical significance of the changes. From Figure 4 it can be seen that the fairly sharp falls in correlation between BR and mortgage rates that occurred in response to the crisis were subsequently reversed. This, along with small changes in the mean-differences (1.5 percentage points change being the largest), suggests that any loosening of the relationship as a consequence of the financial crisis was short-term and will not have any long-term impact on the extent to which the monetary authorities can influence mortgage interest rates through this channel. The lack of clear consistency in sign and significance found in Table 1a is confirmed in Table 1b which reports that the crisis-period dummy variables show no statistically significant changes in correlation levels.

Table 1a: Statistical location-based hypothesis tests on changes in the conditional correlation between the real base rate and real mortgage rates.

Mortgage rate	Sample length per period	Mean corr. with BR period 1[1]	Mean corr. with BR period 2[2]	Difference in mean corr. with BR	Welch two sample t-test p-value	Wilcoxon rank sum test p-value
3 year fixed	68	0.922	0.937	0.015	0.027**	0.001***
2 year discount	68	0.957	0.955	-0.002	0.313	0.843
standard variable	68	0.966	0.974	0.008	0.028**	0.000***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. [1]68 observations; period runs from December 2001 to July 2007. [2]68 observations; period runs from August 2007 to March 2013.

Table 1b: Regression[1] based hypothesis tests on changes in conditional correlation between the real base rate and real mortgage rates.

Mortgage rate	Sample[3]	Intercept	Crisis DUMMY
3 year fixed	136	0.922***	0.015
2 year discount	136	0.957***	-0.002
standard variable	136	0.966***	0.008

*Significant at 10%, **Significant at 5%, ***Significant at 1%. [1]$C_{i,t} = \mu_i + \delta_i Crisis\ DUMMY_t + \varepsilon_{i,t}$ where: $C_{i,t}$ is the conditional correlation between BR and the mortgage rate (i) and $Crisis\ DUMMY_t$ is a dummy variable taking on a value of 1 from August 2007. Robust (HAC) standards errors (Newey and West, 1994, 1987) have been applied. [3]The 136 observations period runs from December 2001 to March 2013. The restricted sample ensures comparability with Table 1a. Unreported results using the full-period sample of 159 (January 2000 to March 2013) produced similar outcomes.

5.1 Testing Hypothesis 1

The conditional correlations between ‘all areas house prices’ (PALL) and the three real mortgage rates are derived from Model 2 (Appendix 2) and presented in Figure 5. The correlation with the three-year rate, for example, ranges from 0.222 to 0.529. Changes in the conditional values across all three interest rates appear to be largely consistent over time and show evidence of trending upwards over the period of the study. Although the positive correlation relationship is counter to the theoretical expectation, similar findings can be cited elsewhere in the literature. For example, Sutton (2002) identified that house prices had a positive relationship with long term interest rates in the UK from 1980 to 2000. It can also be noted from the charts in Section 2 that the crisis resulted in periods when real house prices and real mortgage rates moved in the same direction.

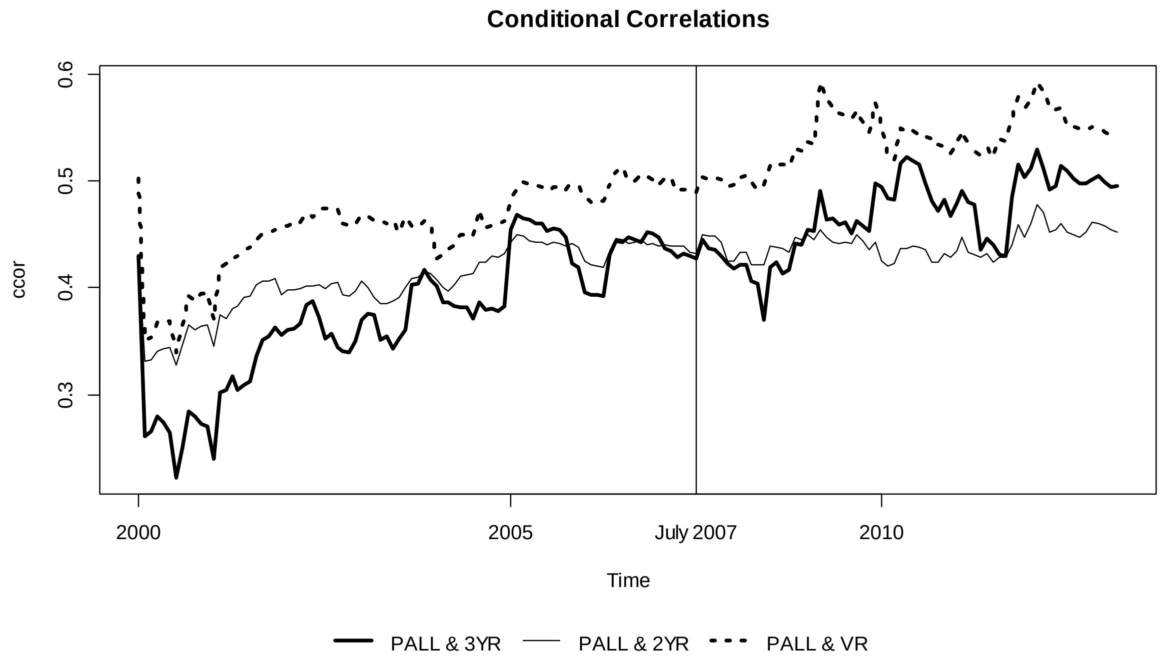


Figure 5: Conditional correlation from January 2000 to March 2013 between real UK house prices (PALL) and: real 3-year fixed rates (3YR), real 2-year discount rates (2YR) and real standard variable rates (VR). All series are adjusted and in fractional difference form. The financial crisis is identified as starting in July 2007 (the vertical line).

Table 2a reports that mean correlations are stronger in the post-crisis period for each of the 3 mortgage interest rates. They increased about 6.6 percentage points for the three-year fixed rate, 6.4 percentage points for the standard variable rate and 2.1 percentage points for the two-year discount rate. The finding that both the Welch and Wilcoxon tests show the mean-differences to be statistical significance for all three rates provides evidence to support hypothesis 1; it suggests a possible permanent adjustment in correlations across England and Wales. Further support for Hypothesis 1 is provided in Table 2b where the crisis-period dummy variable is reported as being positive and statistically significant for 2 of the 3 mortgage interest rates. The third interest rate was also found to be statistically significant on a further test undertaken on the longer 159 month sample period.

The relatively large impact on long-term correlations is possibly a little surprising. One reason is that the fall in real mortgage interest rates (see Figure 1) was, in part, offset by the decline in mortgage availability. A further consequence of the 'credit crunch' was that the fall in the availability of credit also reduced housing supply as potential sellers were unable to obtain the credit needed to 'trade-up' to larger houses (see Section 2). In effect, the fall in demand resulting from the 'credit crunch' also reduced housing supply.

The impact of the diminished supply of mortgage finance has, paradoxically, possibly had more of an effect in the rental market than on house prices. Many first time buyers have had to postpone purchasing a house and have remained in the rental sector. This has resulted in significant increases in rents. For example, The Rentright[28] rental index shows that from July 2007 to August 2012 nominal average rents rose from £879 to £2,405.

Table 2a: Statistical location-based hypothesis tests on changes in the conditional correlation between real mortgage interest rates and real house prices (all areas).

Mortgage rate	Sample length per period	Mean corr. with PALL period 1[1]	Mean corr. with PALL period 2[2]	Difference in mean corr. with PALL	Welch two sample t-test p-value	Wilcoxon rank sum test p-value
3 year fixed	68	0.403	0.468	0.066	0.000****	0.000***
2 year discount	68	0.420	0.442	0.021	0.000***	0.000***
standard variable	68	0.476	0.540	0.064	0.000***	0.000***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. [1]68 observations; period runs from December 2001 to July 2007. [2]68 observations; period runs from August 2007 to March 2013.

Table 2b: Regression[1] based hypothesis tests on changes in the conditional correlation between real mortgage interest rates and real house prices (all areas).

Mortgage rate	Sample[2]	Intercept	Crisis DUMMY
3 year fixed	136	0.403***	0.066**
2 year discount	136	0.420***	0.021
standard variable	136	0.476***	0.064***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. [1]$C_{i,t} = \mu_i + \delta_i Crisis\ DUMMY_t + \varepsilon_{i,t}$ where: $C_{i,t}$ is the conditional correlation between PALL and mortgage rates (i) and *Crisis DUMMY$_t$* is a dummy variable that takes on a value of 1 from August 2007. Robust (HAC) standards errors (Newey and West, 1994, 1987) have been applied. [3]The 136 observations period runs from December 2001 to March 2013. The restricted sample ensures comparability with Table 2a. Unreported results from models run using the full-period sample of 159 (January 2000 to March 2013) found the 2 year discount rate dummy variable parameter to be 0.34 and statistically significant at 5%.

5.2 Testing Hypothesis 2

After finding evidence suggesting that the financial crisis resulted in a possible structural change in the national (England and Wales) correlation relationship we examine the data for possible regional variations in the response. Figure 6 shows there to be regional differences in conditional correlations between 2000 and 2013. For example, three-year fixed mortgage rate correlations with house prices lay between -0.170 and 0.640 in East Anglia, between 0.198 and 0.588 in the South East and between 0.144 and 0.528 in the West Midlands.

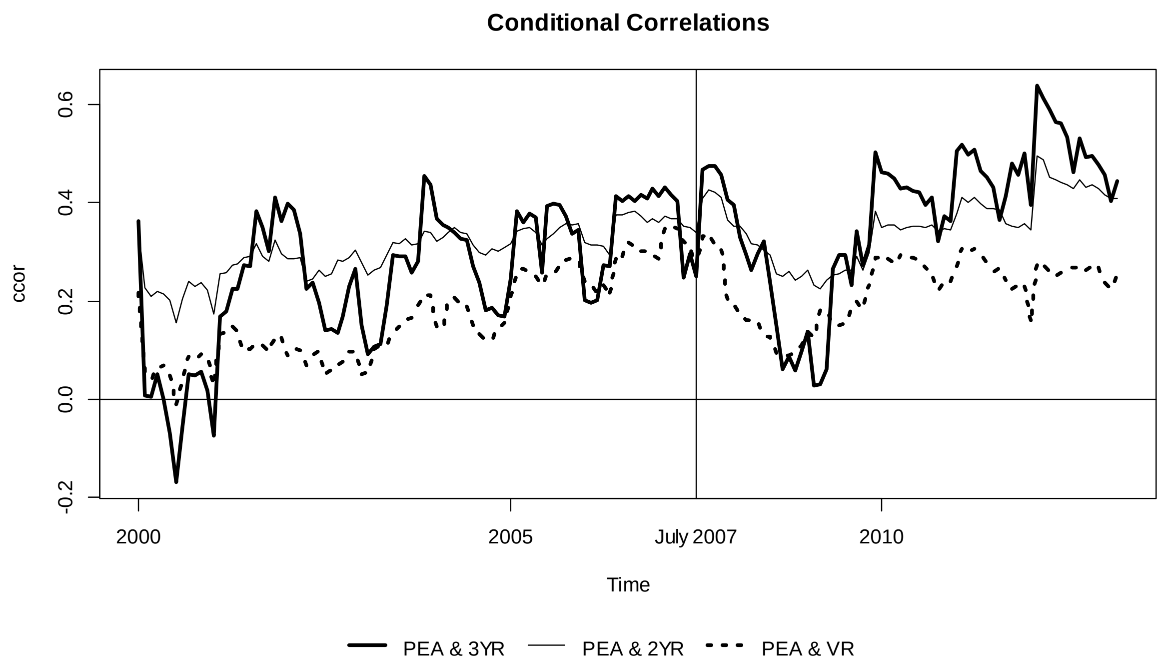
Tables 2a and 2b reported evidence suggesting that nationally (England and Wales) the financial crisis had a positive and largely statistically significant impact on correlations. Table 3 shows statistical significance in a number (but not all) of the regional market pairs in respect to the 'crisis' dummy variable and also strong levels of significance in respect to the location-based tests. It can also be noted that the statistically significant parameters for the

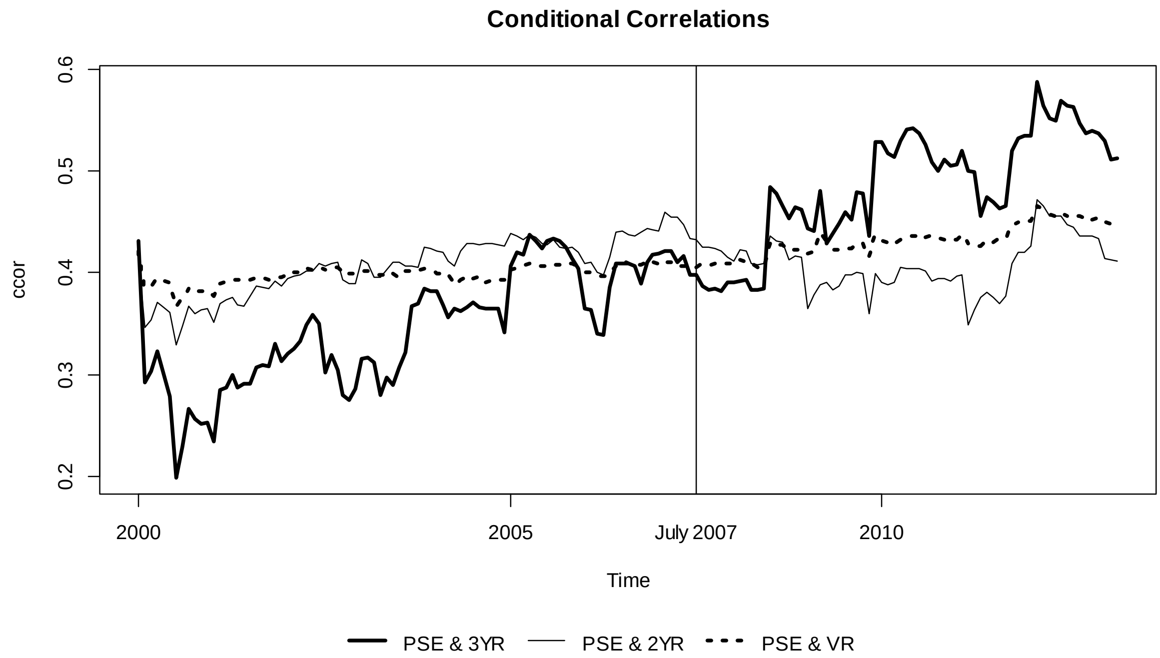
[28] Source: http://www.rentright.co.uk/rrpi.aspx. Access date: 06/09/2012. These values are shown in nominal terms.

dummy variable based tests have a positive sign. For example, an increase of about 14.9 percentage points is reported between the South East and the West Midlands in relation to the three-year rate.

The statistical significance of the majority of the ‘Region’ dummy variable parameters is indicative of the existence of some region-related differences in correlations for all three mortgage rates. For example, this amounts to 20.6 percentage points between the South East and the East Anglia in relation to the standard variable rate.

We formally test the second hypothesis in Table 4 by examining the impact of the crisis on the *ratio* of the regional correlation pairs. We argue that a significant change in this ratio in response to the crisis would be indicative of the crisis having regional variations in its impact. The results from Table 4 are mixed. The location-based hypothesis tests show strong levels of significance in respect to some pairs. However, the results show less significance in respect to the regression-based test variable. It can be observed that, with the exception of the South East-West Midlands pair, the crisis period dummy variable is largely insignificant. From these observations we conclude that we do not have sufficiently strong evidence to support our second hypothesis that structural adjustments in the relationship between real house prices and real interest shows regional variation.





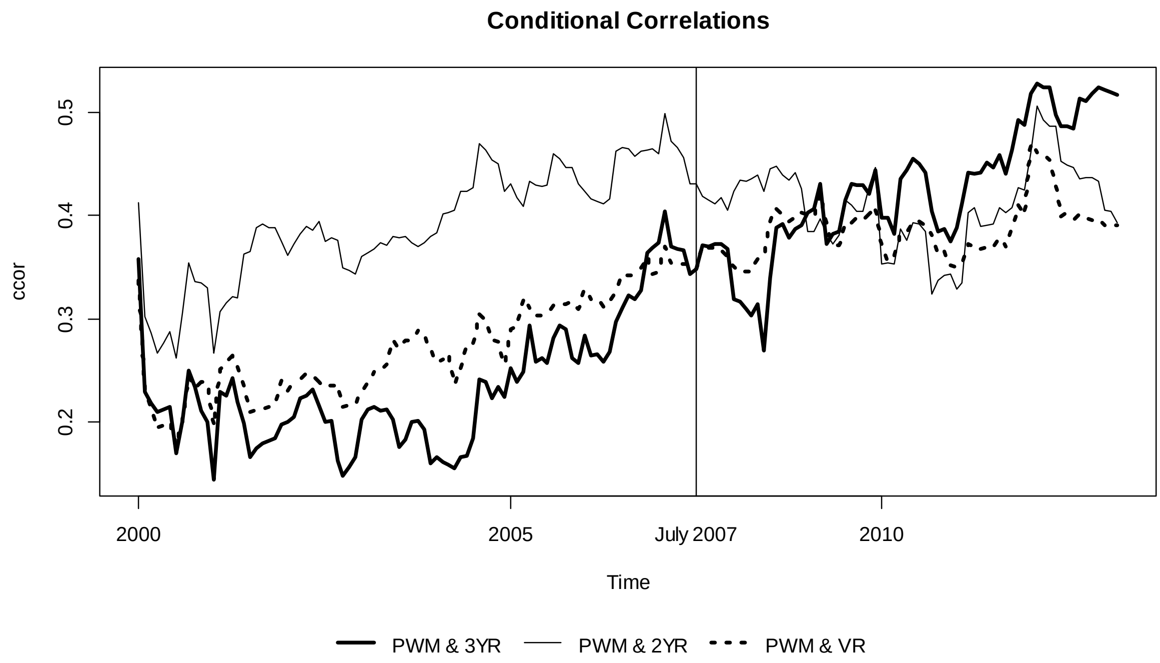


Figure 6: Conditional correlation from January 2000 to March 2013 between real mortgage interest rates (3-year fixed rate (3YR), 2-year discount rate (2YR) and standard variable rate (VR)) and real house prices in East Anglia (PEA), West Midlands (PWM) and South East England (PSE). All series are adjusted and in fractional difference form. The financial crisis is identified as starting in July 2007 (the vertical line).

Table 3: Regression[1] and statistical-location based hypothesis tests on changes in the conditional correlation for selected regional pairs.

Mortgage rate	Regions	Sample length per region[2]	Intercept	Region DUMMY	Crisis DUMMY	Welch[2] two sample t-test p-value	Wilcoxon[2] rank sum test p-value
3 year fixed	E.Anglia & S.East	136	0.377***	-0.088*	0.100**	0.000***	0.000***
	E.Anglia & W.Midlands	136	0.269***	0.004	0.132**	0.000***	0.000***
	S.East & W.Midlands	136	0.261***	0.092**	0.149***	0.000***	0.000***
2 year discount	E.Anglia & S.East	136	0.409***	-0.077***	0.011	0.119	0.156
	E.Anglia & W.Midlands	136	0.405***	-0.075***	0.015	0.051*	0.019**
	S.East & W.Midlands	136	0.416***	0.002	-0.008	0.038**	0.029**
standard variable	E.Anglia & S.East	136	0.402***	-0.206***	0.031	0.028**	0.000***
	E.Anglia & W.Midlands	136	0.305***	-0.126***	0.066	0.000***	0.000***
	S.East & W.Midlands	136	0.306***	0.080***	0.064***	0.000***	0.000***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. [1]$C_{i,j,k,t} = \mu_{i,j,k} + \delta_{i,j,k,1} Region\ DUMMY_i + \delta_{i,j,k,2} Crisis\ DUMMY_t + \varepsilon_{i,j,k,t}$ where: $C_{i,j,k,t}$ is the conditional correlation for regional price pairs (*i, j*) (with respect to mortgage rate *k*), *Crisis* $DUMMY_t$ is a dummy variable that takes on a value of 1 from August 2007 and *Region* $DUMMY_i$ is a dummy variable that takes on a value of 1 for region i (the first region stated in Column 2). Robust (HAC) standards errors (Newey and West, 1994, 1987) have been applied. The 136 observations period runs from December 2001 to March 2013 and corresponds to the period used for the location-based tests. [2]The mean-difference in the correlations between the two sample periods is equal to the value of the crisis period dummy variable.

Table 4: Regression[1] and statistical-location based hypothesis tests on changes in the ratio of conditional correlation for selected regional pairs.

Mortgage rate	Regions	Sample length per region[1]	Intercept	Crisis DUMMY[2]	Welch[2] two sample t-test p-value	Wilcoxon[2] rank sum test p-value
3 year fixed	E.Anglia & S.East	136	0.797***	-0.018	0.682	0.939
	E.Anglia & W.Midlands	136	1.267***	-0.378	0.000***	0.000***
	S.East & W.Midlands	136	1.578***	-0.428**	0.000***	0.000***
2 year discount	E.Anglia & S.East	136	0.762***	0.104	0.000***	0.000***
	E.Anglia & W.Midlands	136	0.775***	0.093	0.000***	0.000***
	S.East & W.Midlands	136	1.019***	-0.017	0.146	0.099*
standard variable	E.Anglia & S.East	136	0.484***	0.042	0.184	0.3074
	E.Anglia & W.Midlands	136	0.650***	-0.058	0.098*	0.076*
	S.East & W.Midlands	136	1.424***	-0.303**	0.000***	0.000***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. [1] $CR_{i,j,k,t} = \mu_{i,j,k} + \delta_{i,j,k} Crisis\ DUMMY_t + \varepsilon_{i,j,k,t}$ where: $CR_{i,j,k,t} = \frac{C_{i,k,t}}{C_{j,k,t}}$ is the ratio of conditional correlations ($C_{i,k,t}$ and $C_{j,k,t}$) between regional price pairs (*i, j*) (with respect to mortgage rate *k*) and *Crisis DUMMY*$_t$ is a dummy variable that takes on a value of 1 from August 2007. Robust (HAC) standards errors (Newey and West, 1994, 1987) have been applied. The 136 observations period runs from December 2001 to March 2013 and corresponds to the period used for the location-based tests. [2]The mean-difference in the ratios of correlations between the two sample periods is equal to the value of the crisis period dummy variable.

6. Conclusions

The question that this paper asks is whether or not the 2007 financial crisis has had a long-term structural impact on the transmission relationship between mortgage interest rates and house prices in the UK. This question is important as it raises issues as to how effective official monetary policy can be in influencing the housing market.

The DCC model applied in this paper uses fractionally differenced data, controls for structural breaks and also controls for a number of non-interest-rate-related house-price-influencing variables. We find that correlations between house prices and mortgage interest rates are largely positive. Although this is contrary to theoretical expectations similar results are found elsewhere in the literature (Sutton, 2002). We also find evidence to suggest that the financial crisis has had a structural impact on the conditional correlation. The impact on correlations across England and Wales as a whole was found to be positive; it increased by 6.6 percentage points in respect to the three-year fixed mortgage interest rate and also by 6.4 percentage points in respect to the standard variable rate. We also find some weak evidence to suggest the existence of regional differences in the response of the transmission relationship to the crisis. However, these findings have limited statistical significance and we therefore conclude that there is no substantive evidence to support the hypothesis of regional variation in the response of correlation to the crisis. We also found some evidence which suggest that the impact of the 'credit crunch' may have been partly displaced into the rental market. Rents have been seen to rise significantly which we suggest may possibly be a response to increases in demand resulting from prospective buyers being unable to finance house purchases[29].

The implications for monetary policy of the impact of the crisis on the housing market have been examined by the Bank of England. Blanchflower (2009) suggested that house prices should be included in the targets that the bank's Monetary Policy Committee considers; this is because of the importance of the housing market in determining overall bank lending. The findings of this paper would suggest that as part of this process the relationship between mortgage interest rates and house prices should not be neglected as the relationship remains a significant one.

[29] Industry data suggests that average rents rose 25% in nominal terms from July 2007 to December 2010 and by 273% in nominal terms to August 2012. Source: http://www.rentright.co.uk. Access date: 15/09/2012.

References

Abelson, P., Joyeux, R., Milunovich, G., Chung, D., 2005. Explaining house prices in Australia: 1970-2003. Economic Record 81, 96-103.

Allen, J., Amano, R., Byrn, D. P., Gregory, A. W., 2009. Canadian city housing prices and urban market segmentation. Canadian Journal of Economics 42, 1132-1149.

Babikir, A., Gupta, R., Mwabutwa, C., Owusu-Sekyere, E. 2012. Structural breaks and GARCH models of stock return volatility: The case of South Africa. Economic Modelling 29 , 2435-2443.

British Banking Association, 2013. April 2013 Historical Time Series Tables. Accessed from: http://www.bba.org.uk/statistics/article/april-2013-figures-for-the-high-street-banks/high-street-banking/. Access date: 03/05/2013.

Bjørnland, H. C., Jacobsen, D. H., 2010. The role of house prices in the monetary policy transmission mechanism in small open economies. Journal of Financial Stability 6, 218-229.

Blanchflower, D., 2009. The Future of Monetary Policy. Accessed from: http://www.bankofengland.co.uk/publications/Documents/speeches/2009/speech382.pdf. Access date: 17/11/2012.

Bollerslev, T., 1986. Generalized autoregressive conditional heteroskedasticity. Journal of Econometrics 31, 307-327.

Bollerslev, T., Osterrieder, D., Sizova, N., Tauchen, G., 2012. Risk and Return: Long-Run Relationships, Fractional Cointegration, and Return Predictability. Journal of Financial Economics, forthcoming. Accessed from: http://www.owlnet.rice.edu/~ns10/risk_and_return.pdf. Access date: 07/12/2012.

Bouchouicha, R., Ftiti, Z., 2012. Real estate markets and the macroeconomy: A dynamic coherence framework. Economic Modelling 29, 1820-1829.

Cappiello, L., Engle, R. F., Sheppard, K., 2006. Asymmetric dynamic in the correlations of global equity and bond returns. Journal of Financial Econometrics 4, 537-572.

Celık, S., 2012. The more contagion effect on emerging markets: The evidence of DCC-GARCH model. Economic Modelling 29, 1946-1959.

Choi, K., Zivot, E., 2007. Long memory and structural breaks in the forward discount: An empirical investigation. Journal of International Money and Finance 26, 342–363.

Dajcman, S., 2012. The Dynamics of Return Comovement and Spillovers Between the Czech and European Stock Markets in the Period 1997–2010. Czech Journal of Economics and Finance 62, 368-390.

Ding, Z., Granger, C. W. J., Engle, R. F., 1993. A long memory property of stock market returns and a new model. Journal of Empirical Finance 1, 83-106.

Engle, R. F., 2002. Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. Journal of Business and Economic Statistics 20, 339–350.

Engle, R. F., 1982. Autoregressive conditional hetroscedasticity with estimates of the variance of United Kingdom inflation. Econometrica 50, 987-1007.

Engle, R. F., Ng, V. K., 1993. Measuring and testing the impact of news on volatility. Journal of Finance 48 , 1749-1778.

Engle, R. F., Sheppard, K., 2001. Theoretical and empirical properties of dynamic conditional correlation multivariate GARCH. NBER Working paper 8554.

Fitzpatrick, T., McQuinn, K., 2007. House prices and mortgage credit: empirical evidence for Ireland. The Manchester School 75, 82-103.

Ghalanos, A., 2013a. Introduction to the rugarch package. Accessed from: http://cran.r-project.org/web/packages/rugarch/vignettes/Introduction_to_the_rugarch_package.pdf. Access date: 13/06/2013.

Ghalanos, A., 2013b. rmgarch: Multivariate GARCH models. Accessed from: http://cran.r-project.org/web/packages/rmgarch/index.html. Access date: 18/05/2013.

Gilchrist, S., Leahy, J. V., 2002. Monetary policy and asset prices. Journal of Monetary Economics 49, 75-97.

Giuliodori, M., 2005. The role of house prices in the monetary transmission mechanism across European countries. Scottish Journal of Political Economy 52, 519–543.

Glosten, L. R., Jagannathan, R., Runkle, D. E., 1993. On the relation between the expected value and the volatility of the nominal excess return on stocks. Journal of Finance 48, 1779-1801.

Goodhart, C., 1995. Price stability and financial fragility. In: Sawamoto, K., Nakajima, N., Taguchi, H., (eds.), Financial Stability in a Changing Environment. Macmillan, London, 439-510.

Goodhart, C., Hofmann, B., 2008. House prices, money, credit and the macroeconomy. Working Paper Series 888, European Central Bank.

Harris, J., 1989. The effect of real rates of interest on housing prices. Journal of Real Estate Finance and Economics 2, 47-60.

Hatemi-J, A., Roca, E., 2011. How globally contagious was the recent US real estate market crisis? Evidence based on a new contagion test. Economic Modelling 28, 2560-2565.

Hentschel, L., 1995. All in the family: Nesting symmetric and asymmetric GARCH models. Journal of Financial Economics 39, 71-104.

Higgins, M. L., Bera, A. K., 1992. A class of nonlinear arch models. International Economic Review 33, 137-158.

Ho, L. S., Wong, G., 2008. Nexus between housing and the macro economy: the Hong Kong case. Pacific Economic Review 13, 223-239.

Hofmann, B., 2004. The determinants of private sector credit in industrialised countries: do property prices matter? International Finance 7, 203-234.

Javed, F., Mantalos, P., 2013. GARCH-Type Models and Performance of Information Criteria. Communications in Statistics - Simulation and Computation 42, 1917-1933.

Khim, V., Liew, S., 2004. Which Lag Selection Criteria Should We Employ?. Economics Bulletin 3, 1-9.

Lean, H. H., Teng, K. T., 2013. Integration of world leaders and emerging powers into the Malaysian stock market: A DCC-MGARCH approach. Economic Modelling 32, 333-342.

Levin, E. J., Pryce, G. B. J., 2009. What determines the price elasticity of house supply? Real interest rate effects and cyclical asymmetries. Housing studies 24, 713-736.

Ljung, G. M., Box G. E. P., 1978. On a Measure of a Lack of Fit in Time Series Models. Biometrika 65, 297–303.

Mann, H. B., Whitney, D. R., 1947. On a test of whether one of two random variables is stochastically larger than the other. Annals of Mathematical Statistics 18, 50-60.

Mazouz, K., Joseph, N., Palliere, C., 2009. Stock Index Reaction to Large Price Changes: Evidence from Major Asian Stock Indices.Asian-Pacific Finance Journal 17, 444-459.

McClain, K. T., Humphreys, H. B., Boscan, A., 1996. Measuring risk in the mining sector with ARCH models with important observations on sample size. Journal of Empirical Finance 3, 369-391.

Nelson, D. B., 1991. Conditional heteroskedasticity in asset returns: A new approach. Econometrica 59, 347-370.

Newey, W. K., West, K. D., 1994. Automatic Lag Selection in Covariance Matrix Estimation. Review of Economic Studies 61, 631-653.

Newey, W. K., West, K. D., 1987. A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. Econometrica 55, 703-708.

R (2013) The R Project for Statistical Computing. Accessed from: http://www.r-project.org/index.html. Access date: 18/05/2013.

Royal Institute of Chartered Surveyors, 2010. RICS Economics. Accessed from: http://www.rics.org/site/download_feed.aspx?fileID=8374&fileExtension=PDF. Access date: 15/12/2010.

Robson, M., 2003. Housing markets and regional unemployment flows in Great Britain. The Manchester School 71, 132-155.

Savva, C. S., 2009. International stock markets interactions and conditional correlations. Journal of International Financial Markets, Institutions and Money 19, 645-661.

Sawilowsky, S., 2005. Misconceptions leading to choosing the t test over the Wilcoxon Mann-Whitney U test for shift in location parameter. Journal of Modern Applied Statistical Methods 4, 598-600.

Schwert, G. W., 1990. Stock volatility and the crash of '87. Review of Financial Studies 3, 77-102.

Su, J. J., Cheung, W. K., Roca, E., 2012. Are securitised real estate markets efficient? Economic Modelling 29, 684–690.

Sutton, G.D., 2002. Explaining Changes in House Prices. BIS Quarterly Review, 46-55.

Taylor, S. J., 1986. Modelling financial time series. first ed. Wiley.

Tsatsaronis, K., Zhu, H., 2004. What drives housing price dynamics: Cross-country evidence. BIS Quarterly Review, 65-78.

Tsai, H. J., Chen, M. C., 2010. The Impacts of Extreme Events of Dynamic Interactions on Interest Rate, Real House Price and Stock Markets. International Research Journal of Finance and Economics 35, 187- 201.

Van Aarle, B., Garretsen, H., Gobbin, N., 2003. Monetary and Fiscal Policy Transmission in the Euro-Area: Evidence from a Structural VAR Analysis. Journal of Economics and Business 55, 609-638.

Welch, B. L., 1938. The significance of the difference between two means when the population variances are unequal. Biometrika 29, 350-362.

Wilcoxon, F., 1945. Individual comparisons by ranking methods. Biometrics 1, 80-83.

Wilhelmsson, M., 2008. Regional house prices: an application of a two-equation model to the Swedish housing market. International Journal of Housing Markets and Analysis 11, 33-51.

Wong, T. Y. J., Hui, C. M. E., Seabrooke, W., 2003. The impact of interest rates upon housing prices: an empirical study of Hong Kong's market. *Property Management* 21, 153-170.

Wooldridge, J. M., 2009. Introductory Econometrics: A Modern Approach. fourth ed. South-Western Cengage Learning.

Zakoian, J. M., 1994. Threshold heteroskedastic models. Journal of Economic Dynamics and Control 18, 931-955.

Zivot, E., Andrews, D. W. K., 1992. Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. Journal of Business & Economic Statistics 10, 251-270.

Appendix 1: DCC models for the fractional differences of the adjusted real interest rates

	Parameter	Series 1: BR	Series 2: 3YF	Series 1: BR	Series 2: 2YD	Series 1: BR	Series 2: VR
Mean Equations	μ (constant)	0.000	0.001	-0.001	0.000	-0.001	0.000
	γ_1^1 (Series 1_{t-1})	0.318*	-0.251*	0.044	-0.280	0.262	-0.086
	γ_2^1 (Series 2_{t-1})	-0.129	0.583***	0.151	0.534*	-0.047	0.357
	γ_1^2 (Series 1_{t-2})			0.238	0.106		
	γ_2^2 (Series 2_{t-2})			0.034	0.154		
	δ (BREAK)	0.005	0.000	0.007	0.002	0.007	0.003

	Parameter	BR-3YF	BR-2YD	BR-VR
Variance: Base rate	**Model Specification**	TGARCH	TGARCH	TGARCH
	ω	0.000	0.001	0.001
	α	0.041	0.051*	0.042
	β	0.963***	0.952***	0.961***
	η_1	1.000	1.000*	1.000
Variance: Mortgage rates	**Model Specification**	TGARCH	NGARCH	TGARCH
	ω	0.000	0.000**	0.000
	α	0.012	0.000	0.017
	β	0.990***	0.999***	0.985***
	η_1	1.000		1.000
	λ		3.99***	
DCC	α	0.134***	0.111**	0.161**
	β	0.786***	0.466***	0.792***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. Estimation based on 159 observations and uses R (2013) and rmgarch package (Ghalanos, 2013b). A number of diagnostic tests were undertaken. The Q-Statistic (Ljung and Box, 1978) for the standardised residuals is used to test for autocorrelation in the mean equation (undertaken with lags 1 and 5). Rejection of the null indicates the presence of miss-specification errors. The Q-Statistic test on the squared standardised residuals was used to examine for the presence of ARCH effects in the variance equation (undertaken with lags 1, 5 and 10). The LM test (Engle, 1982) for ARCH effects in the variance equation was also undertaken with lags 2, 5 and 10. The Q-statistic test on the standardised residuals indicated an absence of any mean equation misspecification errors. Although the Q-Statistic test on the squared standardised residuals indicated possible ARCH effects in some of the base rate variance equations, the ARCH LM test indicated an absence of such effects in all variance equations.

Appendix 2: DCC models for the fractional differences of adjusted real house prices and mortgage interest rates

	Parameter	Series 1: PALL	Series 2: 3YF	Series 1: PALL	Series 2: 2YD	Series 1: PALL	Series 2: VR
Mean Equations	μ (constant)	0.000	0.000	0.000	0.000	0.000	0.000
	γ_1^1 (Series 1_{t-1})	1.064***	0.128	1.074***	0.118	1.034***	-0.047
	γ_2^1 (Series 2_{t-1})	-0.247***	0.485***	-0.224***	0.571***	-0.247**	0.678***
	γ_1^2 (Series 1_{t-2})	-0.141	-0.455***	-0.160	-0.416**	-0.058	-0.195
	γ_2^2 (Series 2_{t-2})	0.081	0.255**	-0.022	0.167	-0.084	-0.027
	γ_1^3 (Series 1_{t-3})	-0.289**	0.501***	-0.238*	0.441***	-0.323**	0.356**
	γ_2^3 (Series 2_{t-3})	0.186*	-0.178	0.285***	-0.184	0.326***	-0.156
	γ_1^4 (Series 1_{t-4})	0.403***	-0.127	0.285**	-0.274*	0.27*	-0.244*
	γ_2^4 (Series 2_{t-4})	-0.226**	-0.222*	-0.132	0.051	-0.146	0.034
	γ_1^5 (Series 1_{t-5})	-0.001	-0.108	0.088	0.117	0.125	0.071
	γ_2^5 (Series 2_{t-5})	0.123	0.275***	0.067	0.088	0.022	0.109
	γ_1^6 (Series 1_{t-6})	-0.349**	-0.062	-0.312**	0.039	-0.261*	0.066
	γ_2^6 (Series 2_{t-6})	0.089	0.069	0.025	0.089	0.078	0.123
	γ_1^7 (Series 1_{t-7})	0.388**	0.382**	0.286**	0.012	0.142	0.002
	γ_2^7 (Series 2_{t-7})	-0.225***	-0.135*	-0.156**	-0.104	-0.126	-0.071
	γ_1^8 (Series 1_{t-8})	-0.223	-0.565***	-0.137	-0.216	0.012	-0.248*
	γ_2^8 (Series 2_{t-8})	-0.006	0.165*	-0.022	0.029	-0.104	0.036
	γ_1^9 (Series 1_{t-9})	-0.064	0.311*	-0.157	0.156	-0.184	0.256*
	γ_2^9 (Series 2_{t-9})	-0.063	-0.333***	0.006	-0.153*	0.033	-0.281***
	γ_1^{10} (Series 1_{t-10})	0.127	0.283*	0.069	0.186	-0.027	0.171
	γ_2^{10} (Series 2_{t-10})	0.008	0.008	-0.014	-0.021	0.036	0.102
	γ_1^{11} (Series 1_{t-11})	-0.180	-0.84***	-0.010	-0.66***	-0.022	-0.818***
	γ_2^{11} (Series 2_{t-11})	0.208**	0.029	0.098	-0.140	0.078	-0.092
	γ_1^{12} (Series 1_{t-12})	0.070	0.269	0.030	0.43**	0.201	0.63***
	γ_2^{12} (Series 2_{t-12})	-0.084	0.316***	-0.018	0.389***	-0.099	0.313***
	γ_1^{13} (Series 1_{t-13})	0.264	0.666***	0.196	0.419**	0.013	0.316*
	γ_2^{13} (Series 2_{t-13})	-0.311***	-0.525***	-0.227***	-0.388***	-0.183*	-0.498***
	γ_1^{14} (Series 1_{t-14})	-0.216	-0.621***	-0.210	-0.676***	-0.117	-0.638***
	γ_2^{14} (Series 2_{t-14})	0.276***	0.218**	0.314***	0.229**	0.357***	0.286***
	γ_1^{15} (Series 1_{t-15})	-0.119	-0.001	0.071	0.295***	0.065	0.265***
	γ_2^{15} (Series 2_{t-15})	-0.093	0.037	-0.195**	0.017	-0.222**	0.020
	γ_1^{16} (Series 1_{t-16})	0.163*	0.240**				
	γ_2^{16} (Series 2_{t-16})	-0.068	0.214**				
	δ_1 (BREAK)	-0.001	-0.002	-0.002	-0.003	-0.002*	-0.003**
	δ_2 (RENTSUB)	0.001	0.003**	0.001	0.004**	0.002	0.004***
	δ_3 ($CONFID_t$)	0.089	0.076	0.093	0.093	0.077	0.039
	δ_4 ($CONFID_{t-1}$)	-0.007	-0.031	0.009	-0.028	0.035	0.022
	δ_5 ($CONFID_{t-2}$)	0.114*	0.071	0.119**	-0.008	0.111*	0.011
	δ_6 ($CONFID_{t-3}$)	0.141**	-0.084	0.088	-0.099	0.103*	-0.046

*Significant at 10%, **Significant at 5%, ***Significant at 1%. Estimation based on 159 observations. The lag length of the endogenous variables was identified using the Hannan-Quinn information criterion.

	Parameter	PALL-3YF	PALL-2YD	PALL-VR
Variance: Prices All Areas	**Model Specification**	GARCH	GJRGARCH	GARCH
	ω	0.000***	0.000**	0.000***
	α	0.099***	0.033**	0.067**
	β	0.790***	0.888***	0.822***
	η_1		0.975***	
Variance: Mortgage rates	**Model Specification**	GARCH	GJRGARCH	GARCH
	ω	0.000	0.000*	0.000
	α	0.002	0.038**	0.002
	β	0.996***	0.794***	0.995***
	η_1		0.983***	
DCC	α	0.022	0.013	0.018
	β	0.931***	0.925***	0.930***

	Parameter	PEA-3YF	PEA-2YD	PEA-VR
Variance: Prices East Anglia	**Model Specification**	GARCH	GARCH	GARCH
	ω	0.000**	0.000	0.000**
	α	0.189**	0.175**	0.147**
	β	0.681***	0.673***	0.706***
	η_1			
Variance: Mortgage rates	**Model Specification**	TGARCH	GARCH	TGARCH
	ω	0.001	0.000	0.003***
	α	0.084*	0.001	0.237***
	β	0.682**	0.997***	0.000
	η_1	1.000		0.271
DCC	α	0.085*	0.028	0.032
	β	0.816***	0.909***	0.908***

	Parameter	PSE-3YF	PSE-2YD	PSE-VR
Variance: Prices South East	Model Specification	GARCH	GARCH	GARCH
	ω	0.000**	0.000	0.000**
	α	0.178***	0.230**	0.162***
	β	0.714***	0.556***	0.662***
	η_1			
Variance: Mortgage rates	Model Specification	GARCH	TGARCH	GJRGARCH
	ω	0.000	0.004***	0.000
	α	0.000	0.119	0.013
	β	0.999***	0.000	0.940***
	η_1		0.724	0.995***
DCC	α	0.025	0.013	0.006
	β	0.938***	0.909***	0.965***

	Parameter	PWM-3YF	PWM-2YD	PWM-VR
Variance: Prices West Midlands	Model Specification	GARCH	GARCH	GARCH
	ω	0.000**	0.000**	0.000***
	α	0.120***	0.074*	0.130**
	β	0.798***	0.841***	0.770***
	η_1			
Variance: Mortgage rates	Model Specification	GARCH	GJRGARCH	TGARCH
	ω	0.000	0.000	0.003***
	α	0.000	0.019*	0.131**
	β	0.997***	0.959***	0.000
	η_1		0.994***	1.000**
DCC	α	0.027	0.026	0.018
	β	0.960***	0.890***	0.957***

*Significant at 10%, **Significant at 5%, ***Significant at 1%. Estimation based on 159 observations using R (2013) and rmgarch package (Ghalanos, 2013b). A number of diagnostic tests were undertaken. The Q-Statistic (Ljung and Box, 1978) for the standardised residuals is used to test for autocorrelation in the mean equation (undertaken using lags 1 and 5). Rejection of the null indicates the presence of miss-specification errors. The Q-Statistic test on the squared standardised residuals was used to examine for the presence of ARCH effects in the variance equation (undertaken with lags 1, 5 and 10). The LM test (Engle, 1982) for ARCH effects in the variance equation was also undertaken with lags 2, 5 and 10. The Q-statistic test on the standardised residuals indicated an absence of misspecification errors in all mean equations. Although the Q-Statistic test on the squared standardised residuals indicated possible ARCH effects in one of the variance equations (PALL-2YD mortgage rate), the ARCH LM test indicated an absence of such effects. All of the tests on the remaining variance equations indicated an absence of ARCH effects.